

Towards a More Accessible Material Platform for Photonic Integrated Circuits: A Hybrid Si_3N_4 -Based Alternative to Thin-Film Lithium Niobate

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Abstract—Thin-film lithium niobate (TFLN) has recently gained prominence in photonic integrated circuits (PICs) due to its excellent electro-optic properties. However, the high fabrication cost, limited CMOS compatibility, and processing complexity present challenges for large-scale deployment. This paper proposes a more accessible and scalable alternative platform, based on low-loss silicon nitride (Si_3N_4) with heterogeneous integration of active electro-optic materials such as barium titanate (BTO), aluminum nitride (AlN), and thin LiNbO_3 itself. We analyze and compare performance metrics including optical loss, electro-optic efficiency, and bandwidth, and outline paths toward CMOS-compatible hybrid PICs with high scalability and minimal power consumption.

I. INTRODUCTION

Photonics is transitioning from lab-scale demonstration to industrial-scale manufacturing, requiring material platforms that are low-loss, CMOS-compatible, and scalable. TFLN offers a high Pockels coefficient and wide optical transparency but remains expensive and challenging to integrate. Silicon nitride (Si_3N_4), in contrast, is already widely adopted for ultra-low-loss passive circuits. This work explores hybrid combinations leveraging Si_3N_4 's scalability with high-performance active materials.

II. MOTIVATION AND HYPOTHESIS

A. Limitations of TFLN

Despite its success in modulators with ~ 100 GHz bandwidth, TFLN suffers from:

- Complex wafer bonding or ion-slicing processes
- High propagation losses outside telecom band
- Difficulties in integration with standard CMOS back-end

B. Hypothesis

A hybrid platform based on Si_3N_4 combined with electro-optic layers such as BTO, AlN, or transferred LiNbO_3 can maintain performance while improving accessibility, loss, and scalability.

III. MATERIAL PLATFORM COMPARISON

IV. HYBRID PLATFORM DESIGN

We propose a layered stack:

- **Substrate:** Thermally oxidized silicon

TABLE I
COMPARISON OF CANDIDATE MATERIALS FOR HYBRID PICs

Platform	Loss (dB/cm)	$V\pi L$ (V·cm)	EO Coeff. (pm/V)	CMOS Comp.
TFLN	0.03–0.2	3–9	~ 30	Partial
Si_3N_4	< 0.01	—	—	Full
Si_3N_4 + TFLN	0.1–1	5–9	~ 30	High
Si_3N_4 + BTO	6–40	0.3–1	~ 900	Moderate
Si_3N_4 + AlN	1–10	~ 10	1–2	Full

- **Passive Layer:** LPCVD Si_3N_4 (200–400 nm) for low-loss guiding
- **Active Layer:** BTO (via pulsed laser deposition) or bonded thin-film LiNbO_3
- **Electrodes:** Coplanar waveguide (CPW) for efficient RF-optical overlap

A. BTO Integration

Recent results show BTO exhibits high Pockels effect but higher optical loss. Mode overlap engineering and surface polishing are under investigation to reduce this.

B. AlN Consideration

AlN offers moderate EO effect with strong thermal and mechanical properties. Suitable for GHz-bandwidth resonator-based modulation.

V. PERFORMANCE PROJECTIONS

Based on simulations and literature:

- Si_3N_4 + TFLN hybrid: loss < 1 dB/cm, $V\pi L \sim 5$ –9 V·cm, 100 GHz BW
- Si_3N_4 + BTO: $V\pi L \sim 0.3$ V·cm, potential for ultralow power
- Si_3N_4 + AlN: GHz-range modulation with robust integration

VI. DISCUSSION

The choice of hybrid material depends on application priorities:

- **Low power:** BTO preferred
 - **High stability:** AlN preferred
 - **Broad compatibility and proven performance:** TFLN
- CMOS compatibility and foundry support favor Si_3N_4 -based stacks, allowing reuse of existing infrastructure.

VII. CONCLUSION AND FUTURE WORK

Hybrid Si_3N_4 platforms with integrated active electro-optic materials offer a promising path beyond monolithic TFLN. Future work includes:

- Experimental verification of BTO and AlN hybrid modulators
- RF-optical co-design for maximized efficiency
- Transfer printing for scalable heterogeneous integration

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